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INTEGRATED SIMULATION OF ATMOSPHERIC PRESSURES AND DYNAMIC FORCES DURING ACCIDENTAL DECOMPRESSION AND SUBSEQUENT EMERGENCY DESCENT OF HIGH ALTITUDE TRANSPORT AIRCRAFT

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3 February 1975

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Aft Facing Passenger Seats

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

These experiments exposed for the first time human subjects simultaneously to decompression events and to mechanical forces. The selected profiles simulated an accidental decompression and subsequent emergency descent of a high altitude/multi Mach transport aircraft. Using the uniquely versatile centrifuge of the Naval Air Development Center, the volunteers, accompanied by on-board observers, experienced a simulated take off and climbing flight, including a nose up rotation of 22 degrees, a cruising flight of 20 minutes

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20. at 8,000 feet cabin altitude, a decompression up to 37,000 feet within 3 minutes, one minute dwelling time at 37,000 feet, and a linear descent to 8,000 feet within 6 minutes. This decompression profile is identical to "Limit IV", which is identified as "worst possible case" in the SST Tentative Airworthiness Standards, Part 25 of the Federal Aviation Administration. The dynamic simulation included a moderate $+G_z$ load shortly after the decompression event, which simulated the pilot's maneuvers to "ease" from the cruising flight into the emergency descent and a G_x load, which simulated the deceleration in the direction of the flight path, due to the decrease of speed from multi-Mach to subsonic values. The ten subjects underwent the experimental conditions in forward facing and rearward facing position. In half of the experiments the overhead mask delivery mode was employed; in the other half the seatback delivery mode. The masks were presented when the cabin altitude reached 12,000 feet. It was shown that a healthy male population (average age 27.7 years) had no difficulties to reach for and don the mask correctly. The average donning time was 12.2 seconds. Earlobe oximetry and the modified number writing test of Lottig did not reveal hypoxic conditions at any time. The individual preferences of the subjects for seatback mask delivery, overhead mask delivery, forward facing seats and aft facing seats are discussed.

ACKNOWLEDGEMENT

These experiments were possible only by the dedicated cooperation of numerous individuals of the Naval Air Development Center and other organizations in the aeromedical community.

It is unfortunately beyond the scope of this publication to list all these individuals. To name only a few, who contributed significantly to this study: Drs. Stanley R. Mohler and S. J. Gerathewohl of the Office of Aviation Medicine of the Federal Aviation Administration who inspired and provided invaluable advice for this study, which was sponsored by Interagency Agreements DOT FA71 WA1-232 and DOT FA 73 WA1-337.

Dr. J. Robert Dille, Director of the Civil Aeromedical Institute, Oklohoma City, and his staff; Dr. George J. Kidera, Medical Director, United Air Lines; Dr. Ludwig G. Lederer, Medical Director, American Air Lines; and Mr. Aaron Blum, President, Sierra Engineering Corporation, for their advice concerning novel passenger oxygen systems and for having provided representative components for these experiments. Dr. Kidera also kindly authorized a field study at Philadelphia International Airport, where exact measurements of the cabin geometry of several current airliners were taken.

It also must be kept in mind that these experiments exposed for the first time human volunteers to cabin decompression on a turning centrifuge. Thus, in case of a medical emergency, access to the cabin would not have been possible before the centrifuge had stopped and the pressure in the gondola had equalized with the ambient pressure. Although all conceivable safety precautions were taken - as will be described in the body of this report - it must be recognized that the volunteers have submitted to experimental conditions which involved the "risk of the unknown".

The undersigned gratefully acknowledges the dedicated cooperation of these subjects and on-board observers. Their names are listed in alphabetical order: Leroy D. Andersen, HM2; Laurence H. Blackburn, CAPT, MC, USN; Robert L. Bobbett, HM2; Raymond R. Bogdan, LDCR, MSC, USN; Richard L. Bresnahan, HM3; Thomas M. Cooper, LT, MSC, USN; William E. Hatley, HM2; Harold Herskovitz, HM2; Richard W. Hoover, HM2; Russell H. King, HMC; John W. MacCoy, HM1; Hubert E. McKinney, LTCOL, VC, USAF; James F. Reed, HM3; David H. Remsen, HM3; Larry Wiles, HM3; Loys E. Williams, LCDR, MC, USN.

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Harald J. von Beckh, M.D.
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INTRODUCTION

Subject effort entitled "Integrated Simulation of Atmospheric Pressures and Dynamic Forces during Accidental Decompression and Subsequent Emergency Descent of High Altitude Transport Aircraft," consisted of two phases. Phase I included the design and fabrication of the gondola insert and unmanned testing of the hypobaric gondola exposed to the desired pressure and acceleration profiles. Phase II consisted of the actual centrifuge experiments using human volunteers.

Phase I was covered by Interagency Agreement DOT FA71WAI-232 (Amendment No. 1). The final report has been submitted and accepted in May 1972.

Since the final report of Phase I has not been published as a Technical Report, its contents for the sake of completeness are synthesized as follows.

Accidental decompression of high altitude aircraft has been the subject of concern for aeromedical investigators for more than three decades. Numerous researchers studied intensively its physiological and psychological aspects by means of exposure of human and animal subjects in hypobaric chambers (1,2,3, 4,5,7,8,9,10,16,17,18,19,23,26,27,29). These static chamber tests, however, could not simulate the dynamic forces which are considerably high during the emergency descent of high altitude multi-Mach transport aircraft (SST type vehicles) (28,32).

More recently, Mohler (22) defined four "limits", i.e. pressure profiles as can be expected in decompression emergencies of SST type vehicles, caused by single or double failure of the pressurization system, skin punctures, loss of cabin windows or door seal elements and combinations thereof. These four limits are the basis for certification of SST type vehicles as formulated in part 25 of the F.A.A. Airworthiness Standards.

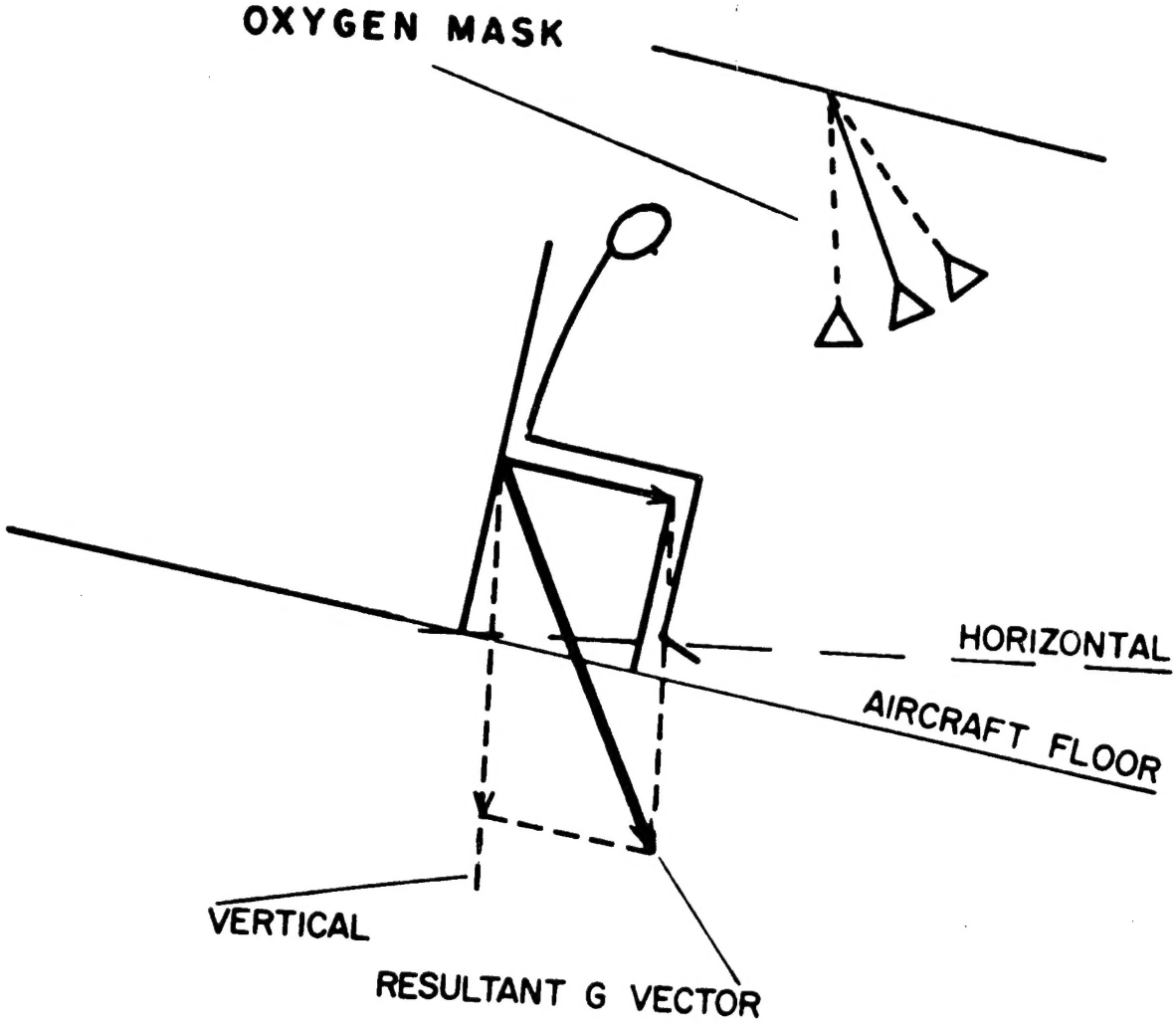


Figure 1. Resultant G vector during emergency descent.

Mohler exposed human volunteers to these four profiles in the hypobaric chamber of the Civil Aeromedical Institute in Oklahoma City (22).

The profile of Limit IV, as "worst possible case," has been used in our centrifuge experiments. (Linear ascent from 8,000 to 37,000 feet within 3 minutes, dwelling time of 1 minute, linear descent to 8,000 feet within 6 minutes). To this pressure profile, however, has been added the dynamic environment of the emergency descent, which is characterized by three realities:

(1) The aircraft's speed will decrease during the descent from multi-Mach values to subsonic speed. This reduction of speed will cause decelerative loads, ($-G_X$) which will tend to displace the occupant into the direction of the flight path. It is expected that these loads will reach or exceed values of $-0.5\ G_X$. It cannot be denied that in future generation SST's these loads may be noticeably higher.

(2) During the descent the aircraft's attitude angle will be negative (nose down). According to the selected flight path its value will fluctuate and may during certain phases of the descent reach or exceed the value of minus 10 degrees. The resultant G-vector will therefore be increased and shifted forward, (Figure 1), i.e., the resulting G load will tend to displace the occupant forward-downward.

(3) During the initiation of the emergency descent additional G loads will originate. The pilot will "ease" into the diving flight by some complex steering maneuvers in order to prevent unacceptable headwards inertia loads ($-G_Z$), which would be produced if he would initiate the emergency dive by a simple pushover maneuver. Several techniques can be adopted for this purpose.

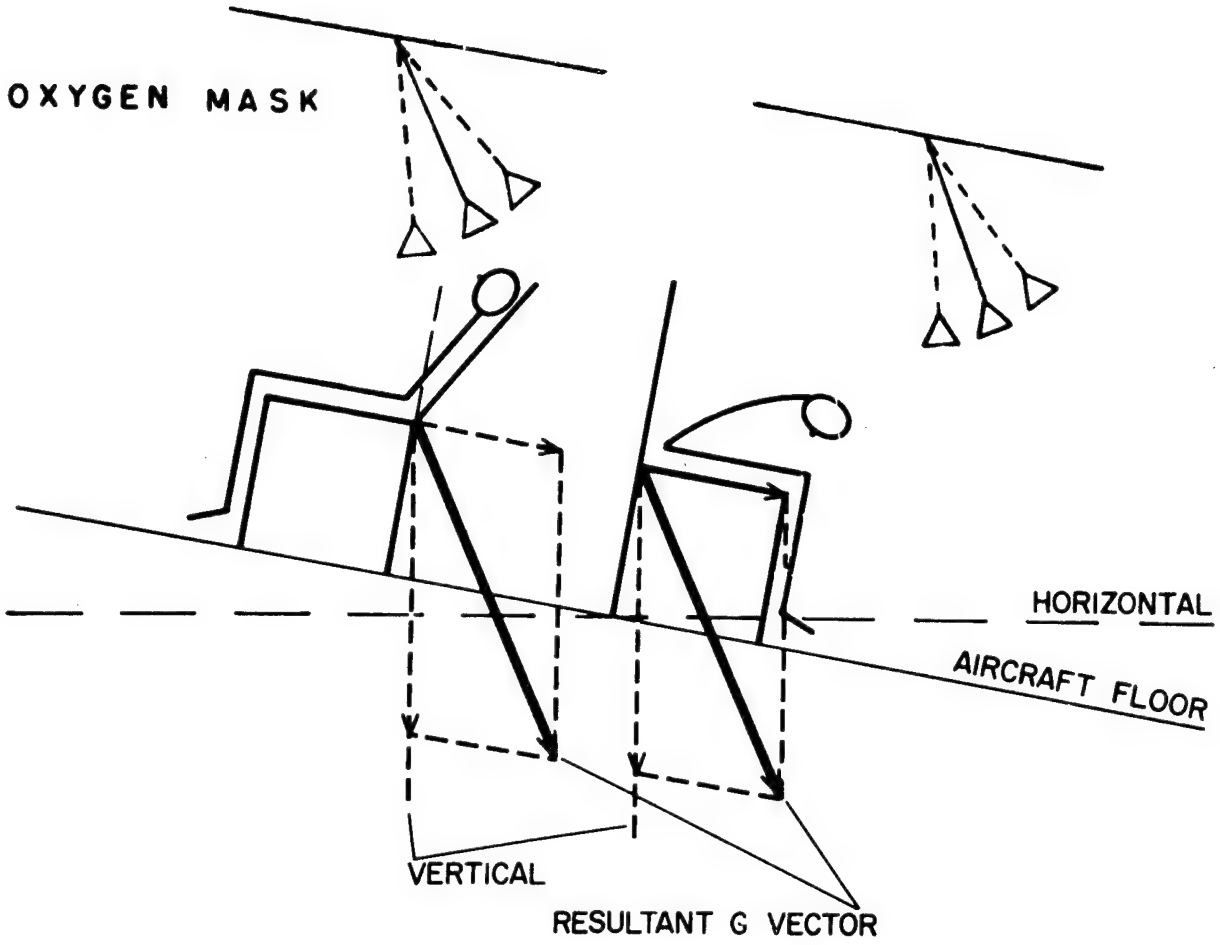


Figure 2. Forward versus aft-facing seats during emergency descent.

They all have in common that they try to absorb $-G_z$ loads by a rolling movement about the X axis of the aircraft, in combination with $+G_z$ loads producing, curved trajectories. Whatever the selected technique may be, some additional G loads must be expected to act upon the occupants during the transition from cruising to the emergency diving flight. Thus, the objective of these centrifuge experiments is to provide answers for the following questions: Will the forward-downward pull cause difficulties for the forward facing subject when reaching for and/or donning the overhead emergency O_2 mask?

Will the aft facing subject have advantages while reaching and/or donning the overhead mask? (See Figure 2). Which advantages if any will the mask presentation by the seatback module offer in comparison with the overhead module? Will the aft facing or the forward facing seat arrangement be more comfortable during emergency descent?

(4) In order to simulate the nose-up rotation of the aircraft when becoming airborne, a backward tilt of the gondola of 22 degrees was performed by computer control during the climbing flight (See Fig. 3).

II. METHODS

1. Centrifuge

The manrated NADC centrifuge was the logical testbed for subject experimentation. Its long arm minimizes undesirable angular and Coriolis accelerations. The computer-controlled double gimbal system, which permits complete rotational freedom of the gondola allows the reproduction of all G vectors as necessary in subject study. The interchangeable capsule concept

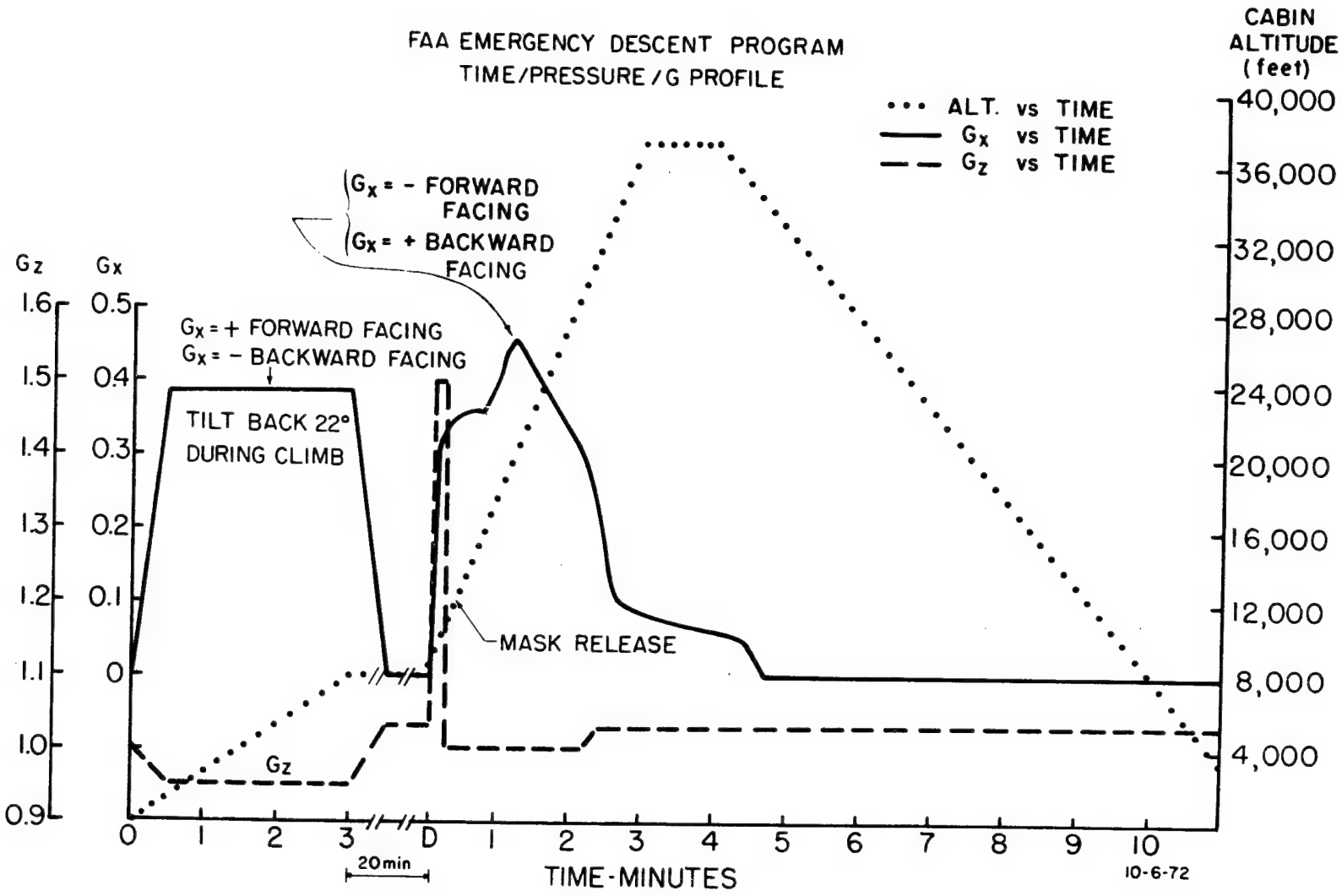

FAA EMERGENCY DESCENT PROGRAM
TIME/PRESSURE/G PROFILE
CABIN ALTITUDE (feet)
ALT. vs TIME
Gx vs TIME
Gz vs TIME
Gx = - FORWARD FACING
Gx = + BACKWARD FACING
Gz
Gx
Gx = + FORWARD FACING
Gx = - BACKWARD FACING
TILT BACK 22° DURING CLIMB
MASK RELEASE
Gz
20min
TIME-MINUTES
10-6-72

Fig. 3

facilitates the insertion of a complete installation which includes such items as needed for subject experimentation, i.e., two passenger type aircraft seats, overhead and seatback type mask delivering modules, control panel, oxygen bottles and related items. This centrifuge is essentially a tubular steel arm, 50 feet long, which is rotated in a horizontal plane about the axis of a vertically-mounted direct current motor with a maximum capability of 16,000 HP, having a maximum torque of 1,700,000 pound foot (lb. ft.) and a maximum speed of 48.5 RPM which corresponds to a maximum G capability of 40 G. The test subjects are enclosed in a spherical gondola, 10 feet in diameter located at the end of the arm (Fig. 4).

The gondola is attached to the end of the arm by means of a two-gimbal system. This gimbal system consists of an outer gimbal which rotates about a horizontal axis perpendicular to the centrifuge arm, and an inner gimbal which rotates about an axis in the plane of the outer gimbal ring and perpendicular to the axis of the outer gimbal. Each gimbal is driven by an electro-hydraulic system located on the arm near its hub. Access to the gondola is provided by means of a retractable platform located in the wall of the 124 ft. diameter centrifuge chamber. The gondola is composed of upper and lower hemispherical fiberglass caps which are attached to a center structural segment. The hypobaric capability of the gondola is achieved when the fiberglass caps are replaced by specially constructed vacuum caps, then producing a spherical hypobaric chamber at the end of the centrifuge arm. Depressurization of this spherical chamber is accomplished by a Beach-Russ vacuum pump located in the utility room on the third deck. The vacuum pump is a Type RP (rotary piston) single stage, high-vacuum pump with a capacity of 430 cubic feet/min. (CFM) of free air. The pump is water cooled and has an automatic lubricating system.

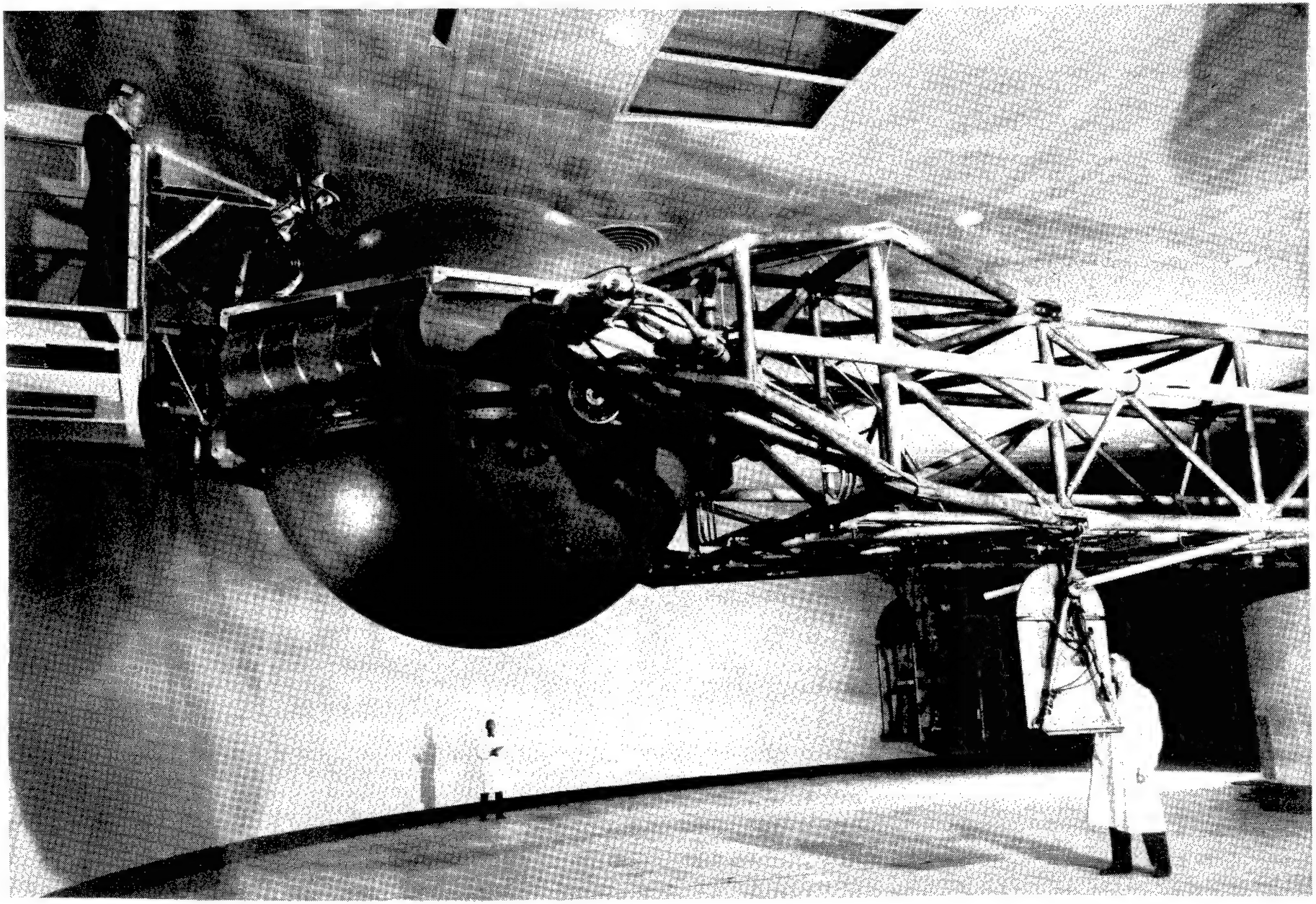


Figure 4. The manrated Centrifuge at the Naval Air Development Center. Its arm measures 50 feet.

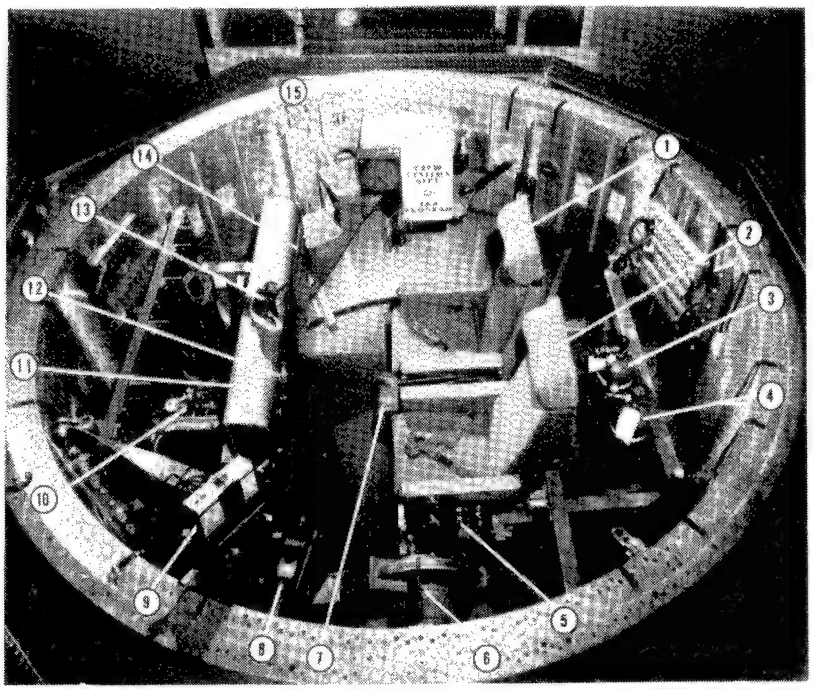
The vacuum pump is connected to the gondola by two 2-inch vacuum lines permanently affixed to the centrifuge arm. Compatability of these lines to dynamic centrifuge operation is achieved by the use of rotary joints located at the main arm hub of the centrifuge and at both the inner and outer gimbal axis. A system of control valves are situated immediately above the centrifuge chamber ceiling on the 3rd deck. The valve system comprises two main control valves and a fail-safe valve. Control of atmospheric pressure and the rate of pressure changes inside the gondola chamber is achieved by operating the vacuum valve and the atmospheric valve along with the continuous operation of the vacuum pump. Maximum pump down of the gondola chamber is accomplished when the vacuum valve is positioned in the full open and the atmospheric valve is positioned in the full closed. The fail-safe valve of the system is an emergency bleed valve. The function of this valve is to move to an open position in the event of a loss of electrical power. All three valves are equipped with rotary manual overrides as an integral part of the valve assembly itself. Control of these valves is however routinely achieved through an electromechanical control system, which is controlled by an analog computer.

A quick action lever type dump valve is located inside the gondola for emergency use by the occupant. During hypobaric operations, the opening of the hatch can only be accomplished when the internal gondola chamber pressure is essentially equalized with the ambient atmospheric pressure. A barometric altimeter is mounted behind the observation port of the hatch so that the internal gondola altitude may be read directly from the loading platform when attempting to ingress the gondola.

2. Design and Manufacture of Gondola Insert

During a field study at the Philadelphia International Airport, exact measurements of the distances between seats and the overhead mask delivery module and the seatback mask delivery module were made. Based upon these measurements the gondola insert was designed and manufactured. On the light-weight/high-strength gondola insert ring structure are attached by means of several cross structures two side-by-side passenger type aircraft seats. The left seat is occupied by the observer, the right seat by the subject. (Since the ingress/egress hatch is located at the right side of the gondola, this arrangement facilitates the egress of the subject in the case of emergencies). The simulated seatbacks of the front row seats carry in front of the subject the seatback mask delivery module and a manual mechanical override to be operated by the observer. Manual overrides are provided for both - the overhead mask delivery module and the seatback mask delivery module - because malfunctioning of the electronic solenoid systems would make the immediate abort of the experiment imperative.

The final configuration of the gondola insert including instrumentation is depicted in Fig. 5, which is an oblique view of the gondola, after the upper hemisphere is removed. The exact cabin geometry is shown in Fig. 6. This cross section of the gondola indicates the exact distances between its main components and shows also the seatback angles of the 3 semireclined and in fully reclined positions.



Oblique view of gondola (the upper hemisphere is removed). 1: subject's seat; 2: observer's seat; 3,4: observer's and subject's O_2 bottle; 5: O_2 and mask delivery selector panel; 6: compression/decompression ports and site for earlobe oximeter; 7: storage bag for medical equipment (Pollitzer bag, atomizer, water container); 8: socket for movie camera; 9: TV camera; 10: O_2 bottle for emergency mask; 11: simulated front row seatback; 12: altimeter and emergency mask regulator; 13: emergency mask; 14: hatch of seatback mask delivery module; 15: access ladder.

Figure 5

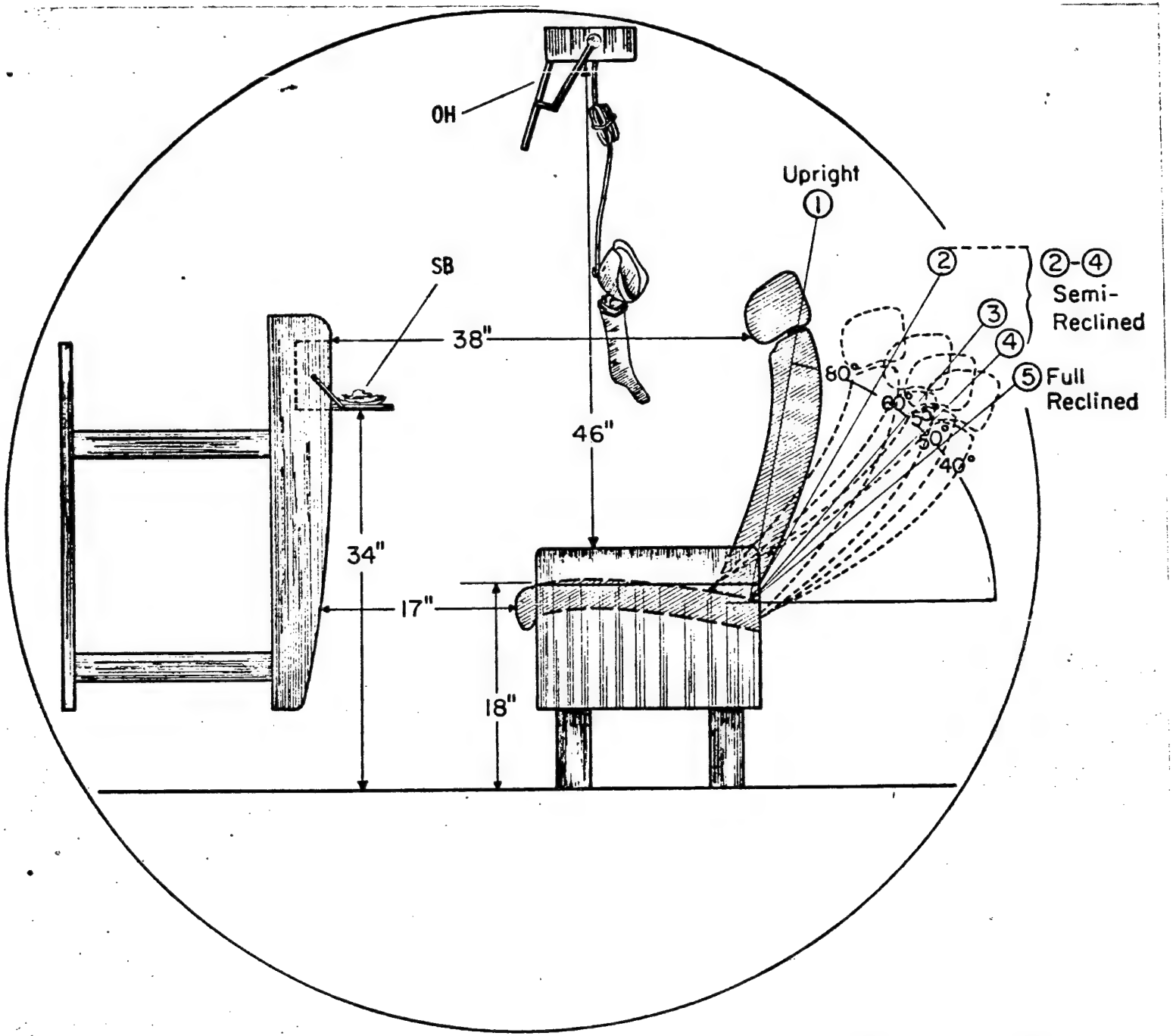


Figure 6. Cabin geometry of gondola insert. SB: Seat back mask delivery; OH: Overhead mask delivery

3. Gondola Oxygen System

The gondola oxygen system consisted of:

- Two 514 cubic inch aviators' breathing oxygen bottles mounted by metal brackets behind the observer (left hand) seat for observer and subject supplies.

- A dilute-demand automatic regulator (Type 2867) and an A-13A mask for the on-board observer.

- A Linde medical oxygen regulator supplying oxygen to a pair of airline passenger masks for the subject (these masks were FAA supplied) of Puritan, pliable plastic types as representative models of those anticipated for installation in supersonic transports.

- Two control panels by the observer's arm rest consisting respectively of controls and indicators for the subject oxygen supply and the observer regulator.

- An emergency system for gondola occupants comprised of a 514 cubic inch aviators breathing oxygen bottle mounted forward of the seatback mock-up, supplying oxygen via a dilute-demand automatic regulator (type 2867 mounted in the seatback facing the observer) and a Sierra Aviators' Mask fixed on the seatback by a quick release strap.

The use of the Sierra Aviators' mask was made practical by its modification with an elastic head strap to facilitate its easy application in the event of inadequacy or complete failure of the subjects routine overhead/seatback mask system.

4. INSTRUMENTATION

a. Earlobe Oximetry

The oximeter utilized in the project was of recent manufacture by the Waters Instruments, Inc., Rochester, Minnesota, Model No. 0-1000. The earpiece transducer used in conjunction with this oximeter was a Waters Model XE-350. Several modifications were performed on this oximeter in order to render the unit suitable for use on the centrifuge. These included:

(1) A box was constructed of Lucite, in order to enhance the ability of the unit to withstand forces imposed by acceleration, with five printed circuit boards comprising most of the electronic circuitry of the instrument enclosed therein, with the assembly being filled with Sylgard Type 184 encapsulating resin. This potting compound, manufactured by the Dow-Corning Corporation, is a clear, elastomeric, self-extinguishing, silicone resin employed in this case to firmly anchor relatively heavy components, e.g. transformers, to the printed circuit boards. Encapsulation of the transformers also obviated the possibility of arcing or corona at reduced pressures. Additional brackets and straps were used to attach the potted assembly to the chassis/cabinet of the oximeter.

(2) In order to lower the output impedance of the oximeter, and hence enhance the transmission of the output signal from the instrument through the slipring stacks, long cables, etc., to recording apparatus, a complementary common-collector amplifier was added to sub-assembly 0104-93. This lowered the output impedance of the oximeter to 150 ohms (from the original output impedance of approximately 10,000 ohms). Inaddition, the output connector

(JR105) was changed from a 1/4 inch phone jack to a BNC receptacle. Several resistors and an output gain potentiometer were removed from the circuit.

(3) The digital display (Triplett No. 4228N Digital Meter) was removed from the front panel because it was felt that this meter could withstand neither the G nor the depressurization aspects of the experiments.

(4) In the rectangular hole left vacant by the removal of the digital meter was installed an aneroid pressure gage (removed from a sphygmomanometer) and a hose fitting for the attachment of the bulb required to inflate the transducer diaphragm. Tubing was also routed inside the oximeter package to another hose fitting on the rear panel to which the transducer is connected. A Lucite panel was attached over the front-panel pressure gage with a red line inscribed at the point of proper transducer inflation pressure (200 mm Hg).

(5) A small incandescent bulb on the front panel of the oximeter, used to indicate "Lamp Error" was replaced with a red light-emitting diode, Monsanto Type MV5026. This modification results in a more secure mounting arrangement for the indicator as well as providing a virtually infinite life expectancy of the indicator.

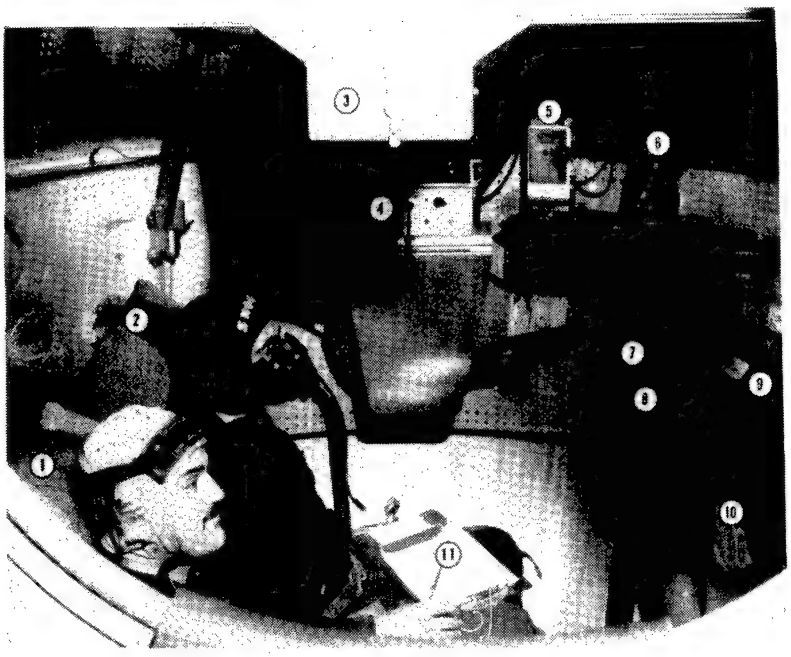
(6) A twenty-foot long extension cable, consisting of a four-conductor cable with locking connectors, and a length of polyethylene tubing, was fabricated so that the oximeter control box could be mounted unobtrusively in the gondola.

b. Electrocardiography

ECG monitoring during this program had as its primary purpose the monitoring of heart rate data and the identification of gross anomalies, if any, rather than the analysis of specific wave forms. A quick-release three electrode system, with the third being an indifferent or common electrode, was utilized in conjunction with a Biocom Model 121 Bioamplifier, modified to meet the safety standards of the American Heart Association, and a Brush Multichannel Recorder Model 481. Both the subject and observer ECG's were monitored with the above equipment at the Medical Monitor's station on the centrifuge Flight Deck throughout the pre- and post-run periods as well as during the actual run itself. At no time during the series of 20 manned dynamic runs were cardiac arrhythmias necessitating the termination of any run recorded.

c. Television and Cinematographic Observation

The subject during decompression was continuously monitored by means of a television camera (Panasonic Model WV-240P) mounted within the gondola and viewed at the stations of the Pressure Monitor on the Flight Deck. In addition, video tape recording of decompression-recompression events using the above camera in conjunction with a video tape recorder (Sanyo VTR 1200) was performed. Together with the subject, the observer and the gondola contents, including a clock showing the elapsed time since the decompression event were also monitored. In addition, a computer controlled motion picture camera Mitchell Monitor 600, mounted side-by-side with the TV camera, took motion pictures of subject and observer during the entire decompression/recompression phase. (Fig. 7)



View of gondola interior through entrance hatch. 1: subject; 2: observer; 3: overhead mask delivery module; 4: earlobe oximeter with calibration bulb; 5: movie camera; 6: TV camera; 7: altimeter; 8: emergency mask regulator; 9: emergency mask; 10: hatch of seatback mask delivery module; 11: writing pad for the Lottig Test.

Figure 7

d. Voice Recording

Subject and observer were in continuous voice communication with the Project Officer, Flight Director, Medical Officer and Centrifuge Computer Operator throughout each run. Each subject was fitted with a recently-developed U.S. Navy Aviator's throat-mounted microphone allowing him freedom of movement in donning the oxygen masks upon decompression. Observers were equipped with the standard U.S. Navy Aviators A-13A oxygen mask with an in-mask microphone. Two-way communication was made possible by means of an in-gondola speaker mounted above and lateral to the subject within the framework of the gondola.

5. Unmanned Dynamic Operation of Centrifuge

Although the centrifuge has had a hypobaric capability since 1956, pressure profiles like those prescribed for the present experimentation have never before been reproduced. Although they are within the specification of the centrifuge, it was imperative to prove that the centrifuge was capable of producing the desired profiles with sufficient accuracy: seventeen unmanned centrifuge runs proved that the system simulates the dynamic and pressure profiles satisfactorily. This effort included: removal of the normally used hemi-spheroid fiberglass caps from the central ring structure and installation of the pressure proof hypobaric metal caps, which are tested for a differential pressure of 29.3 p.s.i.; installation and calibration of transducers for acceleration, barometric pressure and temperature; programming of analog computer for G vectors for both the forward facing and aft facing seat arrangement; static and dynamic check of pressure controls; computer programming and checkout; and testing of total system and system response to acceleration and pressure drive signals.

6. Human Experiments

The fact that never before human volunteers have been exposed on centrifuges to atmospheric pressure changes and dynamic forces simultaneously made numerous safety precautions necessary. They were based upon the assumption that in case of emergencies, immediate access into the gondola was not feasible because of the movement of the centrifuge and the decreased pressure in the gondola. These safety requirements have been formulated by two different groups of individuals: (1) the Crew Systems Department (CSD) Medical Safety Committee, under the chairmanship of this author, which was responsible for all biomedical aspects of the project, (2) an Ad Hoc Technical Multi-disciplinary Safety Review Committee for the FAA Centrifuge Program, under the chairmanship of Mr. A.A. Little. The primary objective of this committee is stated in the Director, Crew Systems Department memoranda appointing committee members. It is as follows:

"This committee is assigned the responsibility of reviewing all phases of the FAA centrifuge program from the technical and safety aspects to ensure compliance with all regulations and practices pertaining to combined hypobaric-acceleration operations. It will audit and document the quality control and testing of all equipments, systems, procedures, and training in terms of safety of manned dynamic operations in this project. The primary goal will be safety of the human volunteers. The committee has the prerogative of requiring whatever information, tests, etc. are necessary to positively assure the committee as to the safety of the project in compliance with pertinent regulations."

In order to assure the members of this committee complete independence

in its decisions, project personnel were not included on the committee. Membership was as follows:

DISCIPLINE	MEMBER	POSITION
Aviation Medicine	LCDR L.E. Williams, MC, USN	Head, Aeromedical Lab.
Aviation Physiology and Altitude Chamber Management	LT T. Cooper, MSC, USN	Aviation Physiologist, CSD, Philadelphia
Centrifuge Test Management and Flight Safety	Mr. D. Morway	Centrifuge Flight Director
Electrical and Electronic Systems	Mr. G.E. Bergey	Electrical Engineer (Instrumentation)
Mechanical and Structural Systems (Committee Chairman)	Mr. A.A. Little	Special Assistant to Director

The committee reviewed in detail seven key areas which were new or modified for this program: Hypobaric System; Oxygen System; Operational Procedures; Electrical System and Instrumentation; Mechanical/Structural System; Subject/Observer Care; and General Items.

The Medical Safety Committee, CSD, formulated the following stipulations:

(a) Each prospective subject or observer has to undergo previous to the beginning of the experiments, the pressure profile and the dynamic profile separately. The pressure profile was simulated in the CSD Static Pressure Chamber at the Philadelphia Navy Yard. The dynamic profile was simulated on the NADC Centrifuge.

(b) The observer would undergo 30 minutes denitrogenation at 100% oxygen prior to decompression.

(c) In order to assure treatment of ear and sinus blocks which might occur during the pressure changes, a pollitzer bag, medical atomizer and a plastic water container were requested to be located on a place easily accessible for observer and subject.

EXPERIMENTAL CONDITIONS AND AGE OF SUBJECTS

SUBJECT	AGE	DATA RUN NO.	DIRECTION OF RUN		MASK DELIVERY	
			Forward Facing	Backward Facing	Overhead	Seatback
RRB	39	2, 13	+	+	++	
TMC	28	8, 18	+	+		++
RHK	32	6, 16	+	+		++
HEM	42	7, 17	+	+	++	
DHR	22	5, 14	+	+		++
LDA	27	3, 12	+	+		++
RWH	21	4, 9	+	+	++	
HH	23	15, 19	+	+	++	
RLB	20	1, 10	+	+		++
LW	23	11, 20	+	+	++	

TOTAL: No. of Subjects - 10

Forward Facing Runs - 10

Backward Facing Runs - 10

Overhead Mask Delivery - 10

Seatback Mask Delivery - 10

Table 1

(d) All inside observers, had to be rated Flight Surgeons, Physiological Training Officers (P.T.O.'s) or Aerospace Physiology Technicians (A.P.T.'s).

The Technical Multi-disciplinary Safety Review Committee completed a painstaking study which ranged from the prevention of fire hazards to the assessment of the structural integrity of the pressure gondola and the centrifuge arm. Numerous corrective actions were considered mandatory and have been implemented. A very complete 60 page final report of the Committee's activities has been prepared by its Chairman, A.A. Little. The interested user can obtain a copy upon request.

After the CSD Medical Safety Committee and the Technical Safety Review Committee had certified that all recommended actions have been carried out, actual centrifuge experimentation started on 8 December 1972. Between this date and 22 December 1972, the 20 scheduled data runs have been completed.

Ten volunteers underwent the experimental conditions in forward facing and in backward facing position. In half of the experiments the overhead mask delivery mode was employed; in the other half the seatback delivery mode. Table I indicates the experimental conditions and the age of the ten subjects. Table II presents a chronological listing of events of the centrifuge experiments. In the first column, 00:00 Time means computer time, which indicates the time period elapsed from the moment when the gondola starts moving and ascending. In the second column, D- Time means Decompression Time, i.e., it is counted from the instant when decompression from the 8,000 to the 37,000 foot level begins. As indicated in Table II, the subjects performed a number writing test as described by Lottig (*Luftfahrtmed.*, 1:15-19 , 1936). This test has been modified by dividing it in three portions to be performed 18 minutes before and 3 and 6 minutes after the decompression event. (See Appendix A.)

Several months before actual experimentation, the prospective volunteer subjects have been repeatedly briefed about the rationale and the

FAA CENTRIFUGE PROGRAM

00:00 Time (min)	D- Time (min)	Chronological Listing of Events
-10	-33	Instrumented subject and observer seated in capsule.
- 9	-32	Observer selects overhead or seatback mask module
- 7	-30	Observer begins breathing 100% O_2.
- 6	-29	Observer calibrates earlobe oximeter.
- 5	-28	Hatch closure. Countdown begins.
00	-23	Centrifuge starts moving and ascending.
+00:26	-22:34	Gondola is tilted 22° backwards (in forward facing experiment) or 22° forward (in backward facing experiment).
+01	-22	Observer calibrates earlobe oximeter
+05	-18	Subject makes first writing test.
+11	-12	Observer calibrates earlobe oximeter.
+21	-02	Observer calibrates earlobe oximeter.
+22	-01	Observer activates O_2 main switch for subject.
+23	00	Decompression. Gondola clock starts (movement of needle is counterclockwise).
+23:05 to +23:20	+0:05 to +0:20	+1.5G_z acceleration begins and changes gradually to -0.5 G_x acceleration which decreases gradually over the next 4 minutes.
+23:20	+0:20	Mask presentation, subject dons mask. Observer reports over the intercom the exact moment when mask is adequately donned with the words "Mask is donned."
+26	+3	Second writing test.
+29	+6	Third writing test.
+33	+10	Observer calibrates earlobe oximeter.
+34:30	+11:30	Hatch opening.

Table 2

procedures of the experiment. In addition, an Information Sheet for Volunteers has been distributed which is enclosed as Appendix B.

Immediately after each centrifuge run the Project Officer debriefed the subjects. All debriefings have been documented on a Debriefing Form which is enclosed as Appendix C.

III. RESULTS

(1) Since Mohler (22), who exposed humans to identical hypobaric profiles, did not observe any hypoxic symptoms during his chamber experiments, no difficulties related to hypoxia have been expected. As a matter of fact, the recorded data and the observation of the subjects, as well as the evaluation of the Number Writing Tests gave no indication that the subjects of the 20 data runs may have been in a hypoxic state at any time. Also, the earlobe oximeter readings remained above ninety percent with the exception of several time periods of non-functioning, which was presumably caused by displacement of the earlobe transducer.

(2) No sinus or earblocks occurred during the 20 data runs. During the preliminary altitude chamber tests (VIDE Section II/6) occurred one bilateral earblock. This prospective subject, as well as another who was affected by a chronic, recurrent sinusitis, have been excluded from further experimentation.

(3) Several subjects noted the sensation of abdominal fullness, especially 3 minutes after the decompression event, when the cabin altitude reached the 37,000 foot level (163 mm Hg). At this altitude, a given volume of gas expands 4.7 times, as compared with its volume at sea level. This sensation, however, never reached an intensity which would have caused real discomfort. The subjects had been indoctrinated to avoid gas producing food during the day before exposure. (VIDE Appendix B, Information Sheet).

(4) The mask donning times were very fast. They ranged from 8.0 seconds to 18.5 seconds with an average of 12.2 seconds. A comparison of the donning times in the four different experimental conditions indicates for the forward facing position with overhead mask delivery a range from 8.8 seconds to 12.5 seconds (average 10.2 seconds); for the forward facing position with seatback mask delivery, a range from 10 seconds to 18.5 seconds (average 13.1 seconds); for the backward facing position with overhead mask delivery a range from 8.0 to 17 seconds (average 12.1 seconds); and for the backward facing position with seatback mask delivery a range from 8.5 seconds to 21 seconds (average 13.4 seconds). However, as will be shown in the later discussion these mask donning times must be interpreted *cum grano salis*.

(5) The inside temperature of the gondola was measured at ambient level, 8,000 feet, 24,000 feet and 37,000 feet during the ascending arc of the simulated flight profile with the readings in reverse upon recompression and descents.

An average drop in temperature of 7.3°F occurred during the 3 minutes following the beginning of decompression. During the recompression an average increase in temperature of 13.7°F was recorded. In addition to the

physical heat production during recompression and metabolic heat production of subject and observer, this increase was enhanced by the heat production of the strong lights which were necessary for the cinematographic observation. They were turned on at the beginning of the decompression event.

(6) In a general manner the subjects stated that the experiments are "very easy and mild" and there is barely a "real difference" between the four experimental conditions. The detailed debriefing of the subjects immediately after each run revealed however, several preferences with respect to mask delivery and seating arrangement:

(a) During the decelerative phase of the emergency descent they considered the backward facing position more comfortable, because they were "more relaxed" and did not feel the tendency to loose contact with the seatback.

(b) When forward facing, they preferred the seatback mask delivery because the "mask did not move away," and when backward facing, the overhead mask delivery because "the reach was not so long." It is also interesting to note that the backward tilt (22 degrees) during the simulated climbing flight did not elicit a marked preference for the forward facing position.

DISCUSSION

With respect to the mask donning times, it is obvious that these short donning times are different from those to be expected in a mixed airliner population including infants and infirms.

Our subjects have been all in excellent health; as a matter of fact for qualifying as centrifuge subjects they are under continuous medical observation. Tentative plans have been made in cooperation with the Office of Aviation Medicine, FAA, to include a larger population of both sexes in these experiments. Pertinent safety regulations however did not permit this.

In addition, our subjects were certainly not naive, since they had to undergo the pressure profile and the dynamic conditions separately, before experimentation begins. (See Section II/6).

Also, they have been aware when the mask would be presented, since they received by the noise of the extracted air acoustical cues when the decompression event commenced. They knew that at reaching the 12,000 foot level i.e. after 15 seconds, the mask would be presented. Another advantage for our volunteers was, that the overhead mask delivery module was exactly in front and above of the subject, which is not true for all airline passengers.

Some subjects tried to compete with each other in grabbing for and donning the mask in a minimum of time. Some of them succeeded in grabbing the mask as soon as the trap door of the delivery module opened; thus the expected forward respectively backward swinging of the mask could not occur.

Since the objective of this experimentation was not to hold a dexterity contest in grabbing the mask, the Project Officer indoctrinated the subjects to wait several seconds until the displacement of the mask occurred, and then

to grab the mask.

Since the subjects did not all wait for the same periods of time the reported mask donning times cannot be used for a valuable assessment of real time necessary for donning the mask under the 4 different experimental conditions.

Earlier studies (32) with unprotected non-human primates exposed in atmospheric air to similar pressure profiles have shown that the recovery from the decompression and subsequent severe hypoxic stress is faster for subjects in semi-supine position, as compared with those in upright seated positions. These findings suggest that for passengers who have not been able to don an oxygen mask, the backward facing position would be more favorable, because the nose down attitude angle during the emergency descent as well as the concomitant deceleration induced shift of the G vector places the occupant in a semi-supine position.

It must be borne in mind, however, that accidental decompression of airliners, especially those of the intensity of "LIMIT IV" are extremely remote events. In addition, our assumption would apply only for those passengers who have not been able to don the emergency mask.

Thus, it seems not to be warranted to consider aft facing seats for decompression protection alone.

In the case that aft facing seats should be selected for other, i.e. crash worthiness reasons, then it can be assumed that they would provide additional protection for the remote event of accidental decompression.

V. CONCLUSIONS

It has been shown previously by Mohler (22) in altitude chamber experiments that decompression/recompression profiles defined by the FAA as "LIMIT IV" can be easily tolerated by human volunteers and do not produce any hypoxic symptoms.

Thus, it was the rationale of our experiments to explore in dynamic centrifuge operations whether the G_Z and the G_X loads caused by the dynamic characteristics of the emergency descent may cause difficulties in grabbing and donning the emergency mask. The results show that a healthy male population, presented by 10 subjects between 20 and 42 years of age (average age 27.7 years) had no difficulties at all to reach for and don the mask. Each subject was exposed in forward and in rearward facing positions. In half of the experiments the overhead mask delivery mode was employed; in the other half the seatback delivery mode. The cabin geometry has been selected on the basis of measurements in current airliners. The recorded data gave no indication that the subjects of the 20 data runs may have been in a hypoxic state at any time.

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Writing Test
for
Decompression/Recompression Profile (F.A.A.)

D minus 18 minutes

Thomas M Cooper
Full Name

Naval Air Development Center
Organization (Spell out NADC)

1000	999	998	997	996	995	994
993	992	991	990	989	988	987
986	985	984	983	982	981	980

D plus 3 minutes

Thomas M Cooper
Full Name

Naval Air Development Center
Organization (Spell out NADC)

979	978	977	976	975	974	973
972	971	970	969	968	967	966
965	964	963	962	961	960	959

D plus 6 minutes

Thomas M Cooper
Full Name

Naval Air Development Center
Organization (Spell out NADC)

958	957	956	955	954	953	952
951	950	949	948	947	946	945
944	943	942	941	940	939	938

20 Dec 72
Date of Experiment

FAA DECOMPRESSION CENTRIFUGE PROGRAM

Information sheet for volunteers

You are invited to volunteer for this centrifuge program, which has as its purpose the simulation of all dynamic events and pressure changes which are expected to occur in a high-altitude/multi-Mach transport aircraft in the event of accidental decompression. The FAA is sponsoring this program to derive information as to how a passenger in such an aircraft would react and respond to such an event particularly with respect to the ability to properly utilize the emergency oxygen system. This kind of information is very much needed by the FAA in order to provide the basis for eventual certification of SST aircraft operation in the U. S.

As you can see from the attached graph, 26 seconds after the centrifuge begins to move your seat will be tilted backwards (in the forward facing runs) or forwards (in the backward facing runs), in order to simulate the nose-up movement of the aircraft when becoming airborne. During the first 3 minutes you will ascent to a cabin altitude of 8,000 feet. Then you will remain at this altitude for 20 minutes which simulates the cruising flight of the aircraft. At the end of this time period, decompression will commence. Five seconds afterwards, you will be exposed to a +1.5 G_Z load which will gradually, over the next 15 seconds change to a +0.5 G_X load, which will pull you slightly forward (in the forward facing runs) or backwards (in the backward facing runs). The cabin altitude, as you can see from the dotted line in the graph, will ascend during 3 minutes to 37,000 feet, will stay for one minute at this level, and then descend gradually over the next 6 minutes to the 8,000 feet level. The descent will continue to ambient altitude in 1½ more minutes. Then the hatch will be opened, and after egress you will be examined by the Flight Surgeon and debriefed by the Project Officer.

This altitude profile would be hazardous if no oxygen mask would be used. A passenger oxygen mask will be presented when the cabin altitude reaches 12,000 feet, i.e. 20 seconds after the beginning of decompression. The observer will assist you in donning the mask, if necessary. Should this mask malfunction, an emergency mask and oxygen source is available and will be donned with the help of the observer.

The Director, CSD appointed a Safety Board, which over the last few weeks thoroughly investigated all potential hazards, as well as the safety of all components involved in these experiments. Operational instructions have been formulated. Drills for all possible emergencies will be conducted before experimentation begins. This Board certified recently in a formal report to the Director, CSD that all necessary measures have been taken to give reasonable assurance that all hardware and components are in safe operational conditions, and that adequate equipment, facilities, and procedures have been established to care for any emergency that may arise. In addition, the CSD Medical Safety Committee has reviewed the project and recommended to the CSD Director that the project be approved as being necessary, scientifically sound, and reasonably safe. The Director has approved the reports and recommendations of the Safety Board and Medical Safety Committee.

The only discomfort which may result during these experiments is related to the change of the volume of body gases during ascent and descent. With respect to the intestinal gases, this discomfort will be minimized by the fact that you will avoid gas producing food during the day before your exposure. The only, although remote, painful experience which you may have is sudden pains in the ear or the head. (Ear block or sinus block). In this case, the descent will be immediately stopped, and, if necessary the cabin altitude increased. You will have been trained in executing the Valsalva maneuver. Also, in the gondola is stored a Politzer bag and related equipment. The observer will assist you in its use, if necessary. These measures generally cut this uncomfortable experience short.

Bends (pains in the joints) and chokes (chest pains and the desire to cough) are not expected to occur in exposures of such short duration. (The cabin altitude will be only for 6 minutes above 20,000 feet). In the very remote case, that these symptoms would be observed, you will descend immediately to ground level. During all runs the subjects will be under the continual observation and control of the medical officer on the flight deck. He will also give pre- and post-run medical examinations. After the experiments (one run in forward facing, one run in backward facing position), you will be debriefed again by the Project Officer and will be invited to describe your sensations in detail during the different phases of the experiments. These findings will contribute to a better understanding of the problems of accidental decompression in high altitude aircraft.

Note for the user: The graph mentioned in the second paragraph , line 1, is identical with figure 3.

FAA Decompression Program
Debriefing Form for Subjects

Name: _____
Date of Run: _____ Number of run: _____

PLEASE CIRCLE ALL CORRECT ANSWERS. IF YOU NEED MORE SPACE FOR COMMENTS, USE REVERSE SIDE.

1. This was a forward / backward facing run with overhead / seatback mask delivery.

2. 26 seconds after the beginning of the run your seat has been tilted backward (in the forward facing runs) or forward (in the backward facing runs) in order to simulate the nose-up movement of the aircraft when becoming airborne.

   Was this movement uncomfortable? Yes No

3. Answer this question only if this was your second data run

   Was this tilting movement more uncomfortable in the forward or backward facing position?

   Forward facing Backward facing

   Please try to explain the reasons:

4. Shortly after the decompression event you have been exposed to $+G_z$ load which simulated the pilot's maneuvers during the transition from cruising flight to the emergency descent. Was this G load uncomfortable: Yes No

   Please specify your sensations:

5. Answer this question only if this was your second data run.

   Was this $+G_z$ load more uncomfortable in the forward or backward facing position?

   Forward facing Backward facing

   Please specify your sensations:

6. After a few seconds, this G_z load gradually changed to a forward downwards directed G load in the forward facing experiments and to a backward downward G load in the backward facing experiments. Was this G load uncomfortable?

   Yes No

   Please specify your sensations:

7. Answer this question only if this was your second data run:

Was this G load more uncomfortable in the forward or in the backward facing run?

Forward facing Backward facing

Please explain the reason(s) for increased or decreased discomfort:

8. What sensations did you have after decompression began?
   Noise
   Turbulence
   Temperature Change
   Others (specify)

9. Answer this question only if in this run the overhead mask delivery was used:

   (a) Did the forward or backward swinging of the mask make donning more difficult?

   Yes No

   (b) At your estimate, how many seconds passed after the presentation of the mask before you had the mask correctly donned?

   ..... seconds

   (c) In the case that this was your second data run, was it more difficult to grab and don the mask in the forward or backward facing position?

   Forward facing Backward facing

   Please try to explain why:

10. Answer this question only if in this run the seatback mask delivery was used:

   (a) Did you have difficulties to reach for and don the mask?

   (b) At your estimate, how many seconds passed after the presentation of the mask before you had the mask correctly donned?

   ..... seconds

   (c) In the case that this was your second data run, was it more difficult to reach for and don the mask in the forward or backward facing position?

   Forward facing Backward facing

Please try to explain why:

11. Did you have pains in the joints at any time? Yes No

If yes, state when and in which joints.

12. Did you have pains in the chest and/or the need to cough? Yes No

If yes, please elaborate:

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